

**TUNGSTEN RESONANCE INTEGRALS AND
DOPPLER COEFFICIENTS
SECOND QUARTERLY PROGRESS REPORT
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By

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I. PROJECT OBJECTIVES

The objective of this project is to carry out an integrated experimental and analytical study of resonance integrals and Doppler coefficients of various samples of natural tungsten, separated-tungsten isotopes, and UO_2 -tungsten fuel.

Measurements of resonance integrals and Doppler coefficients are made in the 10.6-in. lattice of the Sodium Graphite Reactor Critical Assembly (SGR-CA), in which the flux spectrum in the resonance region is approximately $1/E$. Both reactivity and activation methods are used; the reactivity oscillator is calibrated with the known resonance integral of gold, and in addition, the resonance integral of W^{186} will be measured over a limited temperature range by the activation technique.

Resonance integrals and Doppler coefficients for each sample are being calculated with TRIX-1, a fast-running resonance-integral code. Other methods, such as the RIFF-RAFF and ZUT-TUZ codes, or Monte Carlo calculations, will be used as a check and to investigate some possible problem areas.

II. SUMMARY AND EVALUATION

The spectra of real and adjoint fluxes at the sample position at the center of the Sodium Graphite Reactor Critical Assembly (SGR-CA) have been calculated with a one-dimensional diffusion code using 15 energy groups. Fifteen-group sample cross sections have been calculated for a number of sample materials and sizes. These cross sections, together with the calculated spectra, have been used in a perturbation-theory calculation of sample reactivities and Doppler coefficients. Some sample cross sections have been recalculated by using the cross-section definition appropriate to unperturbed fluxes. Perturbation-theory calculations made by using these cross sections were in good agreement with most experimental results.

Work on a Monte Carlo calculation of resonance integrals and Doppler coefficients has started.

Self-shielding of the $1/v$ contribution to the resonance integral and reactivity effects due to sample thermal expansion have been estimated with the aid of Wigner's rational approximation to the escape probability for a lump. The indicated thermal-expansion effect is quite large for samples not under cadmium.

The first set of radial flux maps using tungsten and gold foils has been completed. Tungsten foils have been fabricated for measurement of the W^{186} resonance integral and Doppler coefficient by activation; preliminary measurements have started.

The reactivity of a natural-tungsten slug has been measured as a function of temperature up to 1250°K, both bare and under cadmium. The measured points lie on a smooth curve with little scatter. Each reactivity is determined with a precision of about 0.002 to 0.004 cents; the maximum reactivity change from room temperature is about 0.12 cents.

Auxiliary measurements have been carried out that demonstrate the insignificance of the effects of scattering by heavy elements in the sample.

Preliminary calibration of the epithermal sensitivity of the oscillator has been carried out with gold and uranium samples. Larger gold samples are expected to become available shortly that should extend the range of S/M further

into the region of interest for tungsten measurements. Recent measurements over a wide range of S/M for gold have been carried out on another project; when they are analyzed, the results should greatly improve the precision of the oscillator calibration.

The first Doppler-coefficient measurements indicate that the methods used are capable of producing consistent, reproducible results with a precision approaching 2% at higher temperatures. More work, both analytical and experimental, needs to be done on certain systematic effects, primarily the thermal-expansion reactivity coefficient. No major problem areas have arisen as yet, and work is proceeding nearly on schedule. Delivery of samples by Oak Ridge has been slower than that which was allowed for in the original schedule, and development of high-temperature ovens on the AEC-sponsored Fast Doppler project has encountered some difficulties. These may retard the schedule somewhat more.

III. PROGRESS DURING REPORT PERIOD

A. THEORY

1. Spectrum Under Cadmium

The 15-group analysis of the SGR-CA described in the previous quarterly progress report has been extended to include the effects of the cadmium sleeve at the test position at the center of the core. This sleeve is present in all resonance-integral and some Doppler-coefficient measurements. Two of the sleeve dimensions used in the calculation, 1.27-in. inside diameter and 0.031-in. wall thickness, were those of the actual sleeve. Because the calculation was one-dimensional, the sleeve was implicitly assumed to have the full core height; whereas, the actual sleeve was only 6 in. high. Results of measurements of identical samples with and without cadmium end caps are almost indistinguishable, as was reported previously; therefore, this approximation should not lead to appreciable error.

Calculations were made by use of the CAESAR code.⁽¹⁾ Cross sections and reactor composition and geometry were identical with those used in the previous analysis,⁽²⁾ except that the central void contained an annulus of cadmium as described above. Ten mesh points were used across the thickness of this annulus. The cadmium-thickness dependence of the low-energy limit of the epithermal spectrum, often described by an effective cadmium cutoff energy, was thus taken into account in detailed fashion.

Cadmium multigroup cross sections were computed as follows. (Energy and lethargy widths of each group are presented in Table 1.) The thermal (group 15) cross section was calculated by averaging pointwise data over a carbon spectrum calculated with TEMPEST.⁽³⁾ Cross sections for both groups 15 and 14 were multiplied by a factor of 0.86 to correct for the difference in flux depression between diffusion theory and transport theory. This factor was computed from a model consisting of an infinite slab of cadmium in an infinite graphite medium. The final values of σ_a (Cd) put into CAESAR were 2600, 118, and 4.0 b, for groups 15, 14, and 13, respectively. Cross sections for the low epithermal groups (12-14) were obtained by averaging pointwise data from the Aldermaston nuclear-data tape over a $1/E$ spectrum. Cross sections for higher-energy

TABLE 1
GROUP STRUCTURE USED IN 15-GROUP CALCULATION

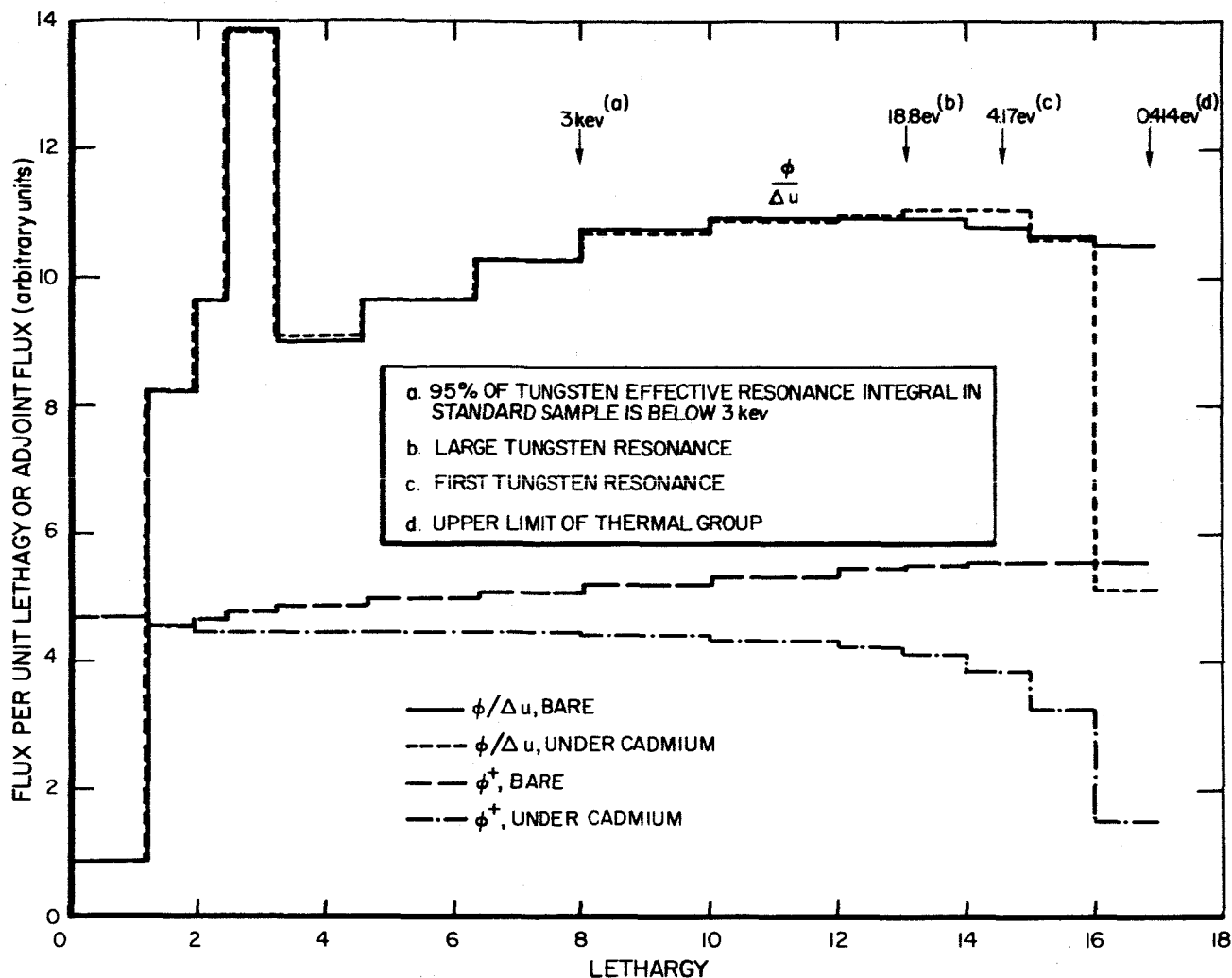
Group No.	Group Boundaries		Group No.	Group Boundaries	
	Energy	Lethargy		Energy	Lethargy
1	10.00 Mev	0	8	3.354 kev	8.000
	3.00 Mev	1.204		0.454 kev	10.000
2	1.40 Mev	1.966	9	61.44 ev	12.000
3	0.90 Mev	2.408	10	22.60 ev	13.000
4	0.40 Mev	3.219	11	8.315 ev	14.000
5	0.10 Mev	4.605	12	3.059 ev	15.000
6	17.00 kev	6.377	13	1.1256 ev	16.000
7	3.354 kev	8.000	14	0.414 ev	17.000
			15	0.0092 ev	20.800

groups were averaged over a carbon spectrum calculated with FORM.⁽⁴⁾ The cadmium resonance integral was assumed to be 40% of its infinitely dilute value; results are insensitive to this assumption.

A comparison of the flux and importance spectra at the test position with and without the cadmium sleeve is presented in Figure 1. The most significant effect of the cadmium is seen to be the reduction in the importance function for the low-energy epithermal groups.

2. Sample Cross Sections

Calculations of expected sample reactivities are carried out with first-order perturbation theory, and require multigroup self-shielded cross sections for each sample, as well as multigroup real and adjoint fluxes. In the resonance region, these cross sections are calculated with the TRIX code.⁽⁵⁾ Multigroup cross sections are defined in terms of fluxes and reaction rates; thus, for the i th energy group, the cross section σ_i is defined as the number that gives the correct reaction rate when multiplied by some average flux ϕ_i . Clearly, the value of σ_i depends on what kind of average flux is used. A standard approximation in the resonance region is to take ϕ_i independent of position (r) and lethargy (u_i); usually more accurate is to set ϕ_i equal to the integral of the



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Figure 1. Calculated Spectra at Sample Position With and Without Cadmium

actual flux over the lethargy width of the group, accounting for flux depletion in the resonances. Both definitions of σ_i are available as options in TRIX. Until recently, the second definition was used for calculating sample cross sections for this project. For first-order perturbation calculations, however, the first definition is the appropriate one, because the cross section is going to be multiplied by the unperturbed flux (i.e., the flux calculated by CAESAR with the sample absent) to obtain the reaction rate. Effective group cross sections for some samples have been recalculated with the definition appropriate to perturbation calculations. By reducing the calculated reactivities,* this

*Since the average flux inside the sample is smaller than the unperturbed flux, the cross section to give the correct reaction rate with this flux is larger than the corresponding cross section for the unperturbed flux, and hence would result in calculated reactivities that were too large.

recalculation has improved agreement with measured reactivities. These results are presented in Table 2 (Columns 5 and 6) and in Table 3, in the next subsection.

3. Calculated Reactivities and Doppler Coefficients

Real and adjoint fluxes from the 15-group CAESAR calculations and 15-group sample cross sections were used in perturbation calculations of sample reactivities and Doppler coefficients with the PERT code.⁽⁶⁾ In addition to the bare and cadmium-sleeve CAESAR analyses discussed previously, two additional CAESAR calculations were carried out to gain further insight into the effects of the cadmium sleeve on reactivity, one with double cadmium wall thickness (0.062 in.) and one with the thermal cross section of cadmium set to zero and epithermal cross sections corresponding to the original 0.031-in. wall thickness. Results of these calculations, together with some experimental results, are given in Table 2.*

The following conclusions can be drawn from a comparison of Columns 2-5 in Table 2.

- a) Epithermal worths are relatively insensitive to cadmium thickness (cf Columns 4 and 5). Small uncertainties in cadmium thickness or cross sections are therefore unimportant.
- b) Fluxes and adjoints calculated without cadmium are inadequate for calculating worths of samples under cadmium even if the thermal contribution is excluded (Columns 2 and 5).
- c) This inadequacy is due to the influence of the large thermal cross section of cadmium, and not to the presence of cadmium in the epithermal region, which depresses epithermal worths by only about 15% (Columns 2 and 3). As noted previously, the epithermal importance function (adjoint flux) is strongly depressed by the cadmium sleeve (Figure 1). This is readily understood on physical grounds; an epithermal neutron inside the sleeve has a good chance of returning to the sleeve as a thermal neutron, after several moderator collisions, rather than causing a fission in the nearest fuel elements (about nine inches away).

*Since it is understood that the effect of absorption on reactivity is negative, the minus sign will be omitted from reactivity values in this and future reports, except when needed for clarity.

TABLE 2*
EPITHERMAL WORTHS AND DOPPLER COEFFICIENTS OF
NATURAL-TUNGSTEN SLUGS

Slug Diameter (in.) Col 1	Calculated Values					Measured Values Col 7
	Bare, Epithermal Only ^{a, b} Col 2	Cadmium Wall Thickness (in.)				
		0.031 ^{a, c} Col 3	0.062 ^a Col 4	0.031 ^a Col 5	0.031 ^d Col 6	
0.438	5.0	4.35	2.25	2.50	2.0	1.95
0.25	1.95	1.70	0.89	0.98	-	0.84
(0.25/0.438)	(0.39)	(0.39)	(0.40)	(0.39)	-	-
Doppler Coefficient (cents/1000°C)						
0.438	0.12	0.215	0.12	0.13	0.10	0.12
0.25	0.052	0.095	0.052	0.057	-	-
(0.25/0.438)	(0.44)	(0.44)	(0.44)	(0.44)	-	-

- a. Sample cross sections used were those appropriate for reactor calculations.
- b. Fluxes and adjoints used were those derived from reactor calculation without cadmium, but thermal-group contribution has been subtracted.
- c. Fluxes and adjoints used were those derived from reactor calculation with 0.031-in. cadmium sleeve present, except that cadmium thermal cross section has been set equal to zero.
- d. Sample cross sections used were those appropriate for perturbation calculations.

*Since it is understood that the effect of absorption on reactivity is negative, the minus sign will be omitted from reactivity values in this and future reports, except when needed for clarity.

The reactivities of samples in the cadmium sleeve, recalculated with cross sections appropriate for unperturbed fluxes, are given in Table 3, along with some experimental worths.

TABLE 3
WORTHS OF SAMPLES IN CADMIUM SLEEVE
OF SGR-CA

Sample (0.438-in. diameter, 4.0-in. long)	Worth (cents)	
	Calculated	Experimental
Natural W	2.0	1.95
W-182	1.4	-
W-183	1.6	-
W-184	0.21	-
W-186	1.6	-
Gold*	1.1	1.195
Depleted U	0.68	0.76

*0.235-in. diameter, 3.683-in. long

Values of the recalculated Doppler coefficient over the range from room temperature to 540°C are 0.10 ϵ /1000°C under cadmium and 0.18 ϵ /1000°C bare.

4. Monte Carlo Calculations

Work on a Monte Carlo calculation of resonance integrals and Doppler coefficients has started. For the most part, this will make use of existing sub-routines. This calculation will allow all cross sections to be put in as explicit functions of energy, temperature, and position. As a result, such effects as deviation from flatness of spatial and lethargy distribution of the neutron flux, as well as interaction between overlapping resonances in different materials, will be taken into account automatically. Data preparation is absorbing most of the effort in this area.

5. Self-Shielding Calculations

Wigner's rational approximation⁽⁷⁾ to the escape probability of a lump has been used to estimate the self-shielding of the nonresonant cross sections in

tungsten and gold samples, and from this, to estimate the effect on reactivity of thermal expansion of the sample.

First, consider the self-shielding of the $1/v$ cross section. In most resonance-integral codes, the $1/v$ contribution to the resonance integral (or to the group cross sections) is assumed to be infinitely dilute. Thus, the effective resonance integral consists of a large, geometry-dependent term and a small, additive, constant term. Although this approximation is excellent in most cases, it is obviously not very good when the lump is so thick that the $1/v$ contribution is a reasonable fraction of the total calculated resonance integral. This is the case for the "thickest" gold sample (0.235-in. diameter by 3.683-in. long) being used to calibrate the SGR-CA oscillator, and possibly for standard-sized tungsten samples as well.

To estimate this effect, assume that the self-shielded $1/v$ contribution to the effective resonance integral is given by

$$I_1 = \int_{E_c}^{\infty} \sigma_1(E) G(\sigma_1) dE/E ,$$

where $I_1(E_c) = 1/v$ contribution for effective cadmium-cutoff energy E_c ,

$\sigma_1(E) = 1/v$ cross section at energy E , and

$G(\sigma_1) =$ self-shielding function for monoenergetic neutrons of energy E and cross section $\sigma_1(E)$.

Next, assume that $G(\sigma_1) \cong \frac{1}{1 + \ell \Sigma_a(E)}$ (Wigner's rational approximation),

where $\ell =$ mean chord length in lump $= 4V/S$,

$V/S =$ volume and exposed surface of lump,

$\Sigma_a(E) = N\sigma_1(E) =$ macroscopic absorption cross section, and

$N =$ density of absorber atoms in lump.

The lump geometry can be conveniently expressed in terms of the parameter s , defined as

$$s = 1/N\ell = S/4NV.$$

The parameter has the dimensions of a cross section, and is equal to one-fourth of the lump surface area per atom. It can be thought of as a cross

section for escaping capture in the lump. The ratio σ_1/s is then a measure of the lump self-shielding: large s implies large escape probability, high dilution (s is directly proportional to S/M), small σ_1/s , and small self-shielding.

Then $\ell\Sigma_a = \sigma_1/s$ and

$$G(E) \cong \frac{1}{1 + \sigma_1(E)/s} .$$

The energy dependence of σ_1 is given by $\sigma_1(E) = \sigma_0 v_0/v(E)$, where $v_0 = 2200$ m/sec and $\sigma_0 = \sigma(v_0)$. When all these substitutions are made, the result of the integration for I_1 is

$$I_1(s, E_c) = 2s \ln(1 + \sigma_c/s) ,$$

where $\sigma_c = \sigma_0 v_0/v(E_c)$ is the $1/v$ cross section at cadmium cutoff.

For a standard-size natural-tungsten sample, $\sigma_0 = 19.2$ b and $s = 14.97$ b; taking the cadmium-cutoff energy E_c from the tables of Stoughton et al.⁽⁸⁾ to be 0.622 eV* yields a correction of 0.86 b to be subtracted from the calculated effective resonance integral of 38.4 b. This result probably overestimates the correction somewhat, mainly because the rational approximation overestimates self-shielding.

In the Doppler measurements without cadmium, thermal expansion of the sample decreases the self-shielding of the thermal-neutron cross section, thereby increasing absorption in the sample. The magnitude of this effect has also been estimated with the rational approximation. The self-shielded value σ_{eff} of the thermal-neutron absorption cross section σ is given by $\sigma_{\text{eff}} = G\sigma = \sigma/(1 + \sigma/s)$. Differentiation yields

$$\frac{1}{\sigma_{\text{eff}}} \frac{d\sigma_{\text{eff}}}{dT} = \frac{2\alpha}{1 + s/\sigma} ,$$

where α is the linear coefficient of thermal expansion of the sample, and T is temperature. For a standard natural-tungsten sample, with $\alpha = 4.3 \times 10^{-6}/^\circ\text{C}$, the above expression has the value $4.6 \times 10^{-6}/^\circ\text{C}$. Taking $\rho = 20$ g for the

*This energy corresponds to a cadmium thickness of 0.062 in., twice the actual wall thickness, since a reactivity measurement cannot distinguish between a neutron captured in the sample and a neutron that leaves the sample and is then captured in the cadmium sleeve. The effective cadmium thickness for a reactivity measurement is thus twice that for an activation measurement.

thermal worth yields an expansion reactivity coefficient, then, of -0.09 cents/ 1000°C . This answer is large enough that it is clear that a more accurate calculation must be done. Two experimental estimates of this effect will be available, the measured reactivity variation due to density variations among several natural-tungsten samples and the Doppler coefficient measured under cadmium. Under cadmium, of course, the expansion effect on reactivity is expected to be negligible.

B. EXPERIMENT

1. Activation Measurements

Radial flux maps using cadmium-covered foils of dysprosium, indium, gold, tungsten, and cobalt as detectors are being carried out. Each of these detectors is sensitive to a different portion of the epithermal spectrum, so that the results of these measurements can be used to test the validity of the calculated flux spectrum. In the 15-group structure used in CAESAR calculations for this project (Table 1), most of the absorption in dysprosium is in group 14; in indium, group 13; in gold, group 12; in tungsten, group 11; and in cobalt, group 10.

One set of maps with tungsten and gold foils was completed during this report period. Results have not yet been compared with calculated values.

Tungsten foils with thicknesses of 0.001, 0.005, and 0.010 in. were turned to 0.438 in. diameter and were weighed precisely by the AI Standards Laboratory. Since resonance overlap with the cadmium covers may interfere with measurement of the Doppler effect in W-186, they will be used only in the resonance-integral measurement. The separate measurement of I and dI/dT , then, will require precise measurements of the foil and sample masses and densities.

The capsule used for measuring slug samples in the Advanced Doppler coefficients project is being modified to accept the tungsten samples with improved centering.

Initial tungsten-foil irradiations were carried out in the SGR-CA to determine optimum irradiation times and counting parameters.

2. Reactivity Measurements

a. Initial Measurements on Heated Samples

A second oscillator tube was assembled for use in elevated-temperature measurements. It is similar to the tube described in the previous quarterly report⁽²⁾ except that it contains no graphite. Provision was made for air flow through the tube and for the exit of thermocouple and heater wires. Two rods, symmetrically located 24-3/8 in. above and below the center of the tube, were welded across the interior of the tube to act as mechanical stops for the sample and dummy ovens. Several extra ovens and hardware for mounting them inside the oscillator tube were fabricated. With this tube in the oscillator, reactivity measurements were carried out on a standard-size natural-tungsten slug at temperatures up to 1251°K, with and without the cadmium sleeve. Similar measurements were carried out with empty sample and dummy ovens, but a poor vacuum in the sample oven prevented heating it above 983°K. Results of these measurements are shown in Figures 2 and 3, with smooth curves (fitted by eye)

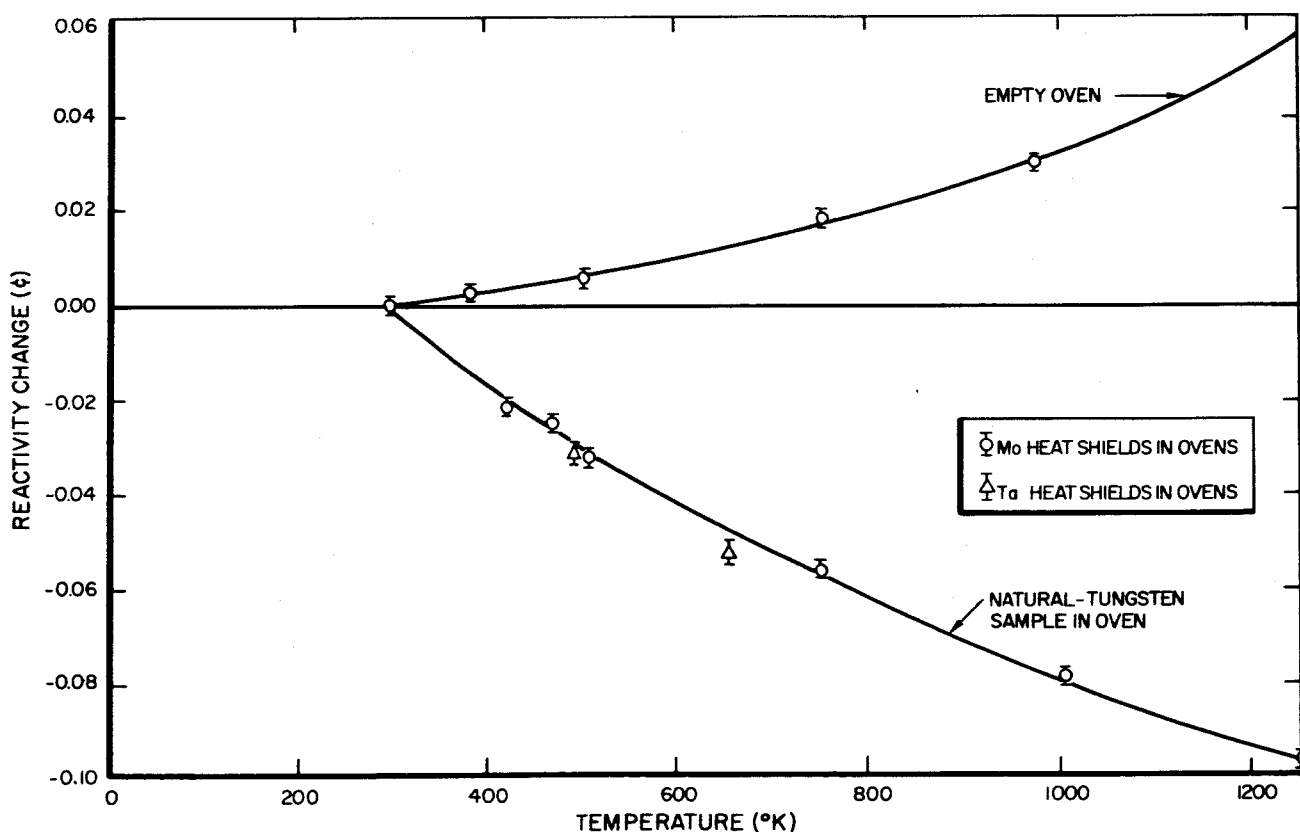
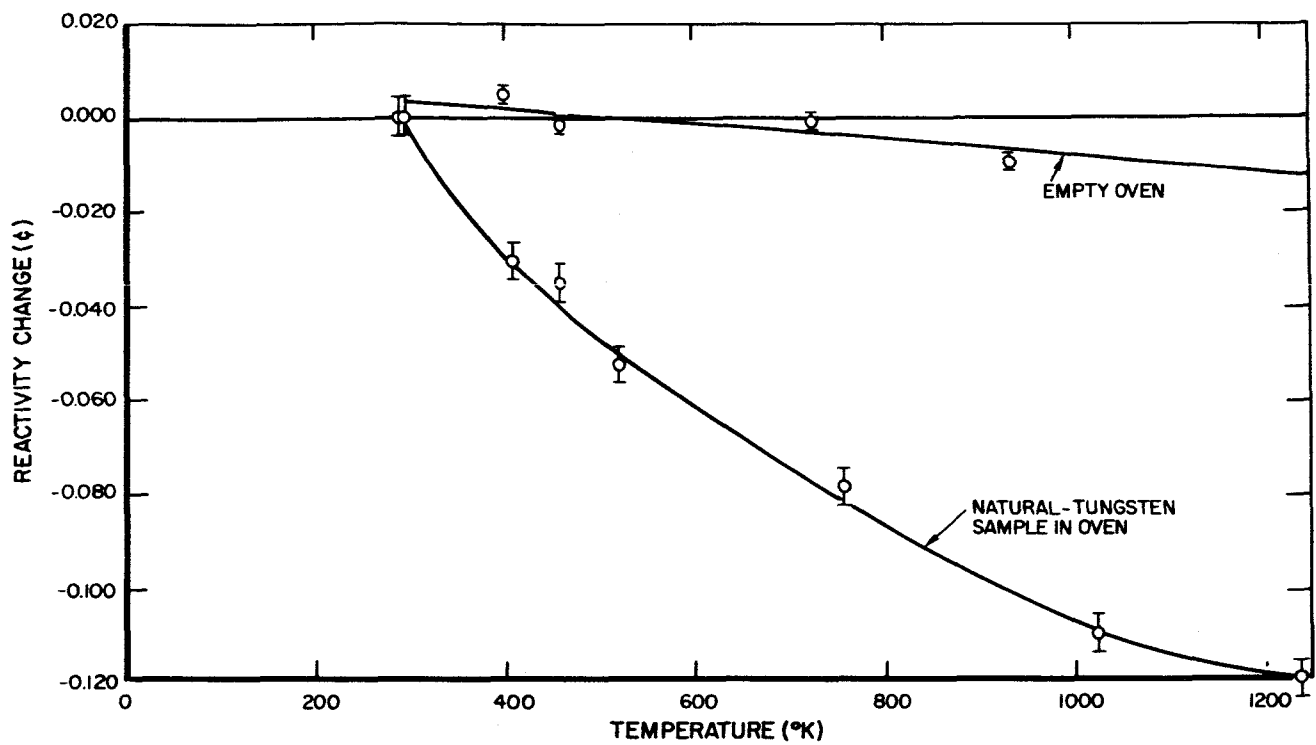


Figure 2. Reactivity Change from Room Temperature vs Temperature (no cadmium sleeve)

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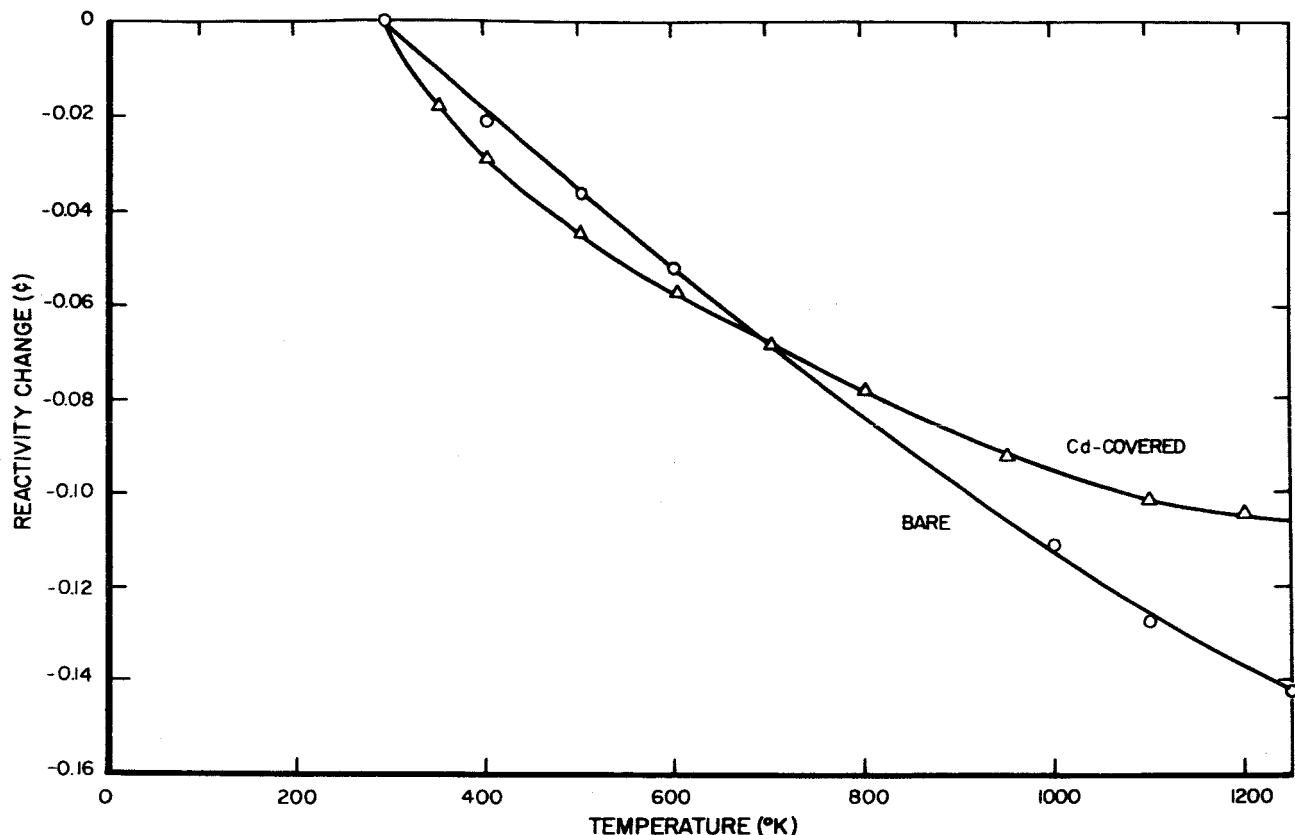
16



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Figure 3. Reactivity Change from Room Temperature vs Temperature (under cadmium sleeve)

drawn through the points. Point-by-point subtraction of the empty-oven curves from the sample curves yields the curves in Figure 4. These represent the net reactivity change of the natural-tungsten sample from room temperature to about 1250°K, both bare and under cadmium. These results are preliminary, not only because of the crude method of arriving at the final curves, but also because of the necessity of making corrections to the data for such effects as thermal expansion, departure of the actual spectrum from the ideal, and possible resonance overlap between cadmium and tungsten. Even without these corrections, it is clear that the average reactivity coefficients of 0.12 (Cd) and 0.15 (bare) $\Delta/1000^{\circ}\text{C}$ derived from Figure 4 are of the same order of magnitude as the calculated values.



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Figure 4. Net Reactivity Change Above Room Temperature, of 0.438-in. Natural-Tungsten Slug after Subtraction of Oven Reactivities

One set of measurements was made with an oven with a tantalum heat shield; all other ovens had molybdenum heat shields. As can be seen from Figure 2, the results are independent of the heat-shield material, within the accuracy of the experiment.

The reactivity of a piece of Lavite oven-insulating material with standard-sample dimensions was measured up to 753°K without cadmium. The reason for this measurement was to exaggerate whatever contribution the Lavite in the oven itself might make to the tungsten temperature coefficient of reactivity. The resulting temperature coefficient was positive and had the value of 0.10¢/1000°C.

b. Auxiliary Measurements

Measurements have been made with the 0.25-in.-diameter natural-tungsten sample surrounded by an additional, thick cadmium cylinder and by a thick lead

cylinder. These results are presented in Table 4, along with the previously measured value for no surrounding cylinder. All these measurements were made in the standard 0.031-in.-wall cadmium sleeve.

TABLE 4
EFFECT OF SURROUNDING CYLINDERS ON
EPICADMIUM WORTH OF 0.25-in. -
DIAMETER NATURAL-
TUNGSTEN SLUG

Composition of Surrounding Cylinder (0.438-in. OD, 0.255-in. ID)	Epicadmium Worth (¢)
Cadmium	0.782
Lead	0.841
None	0.842

Comparison of the lead-cylinder and no-cylinder results again demonstrates the insignificance of heavy-element scattering effects. Most of the 0.06-¢ reduction in worth due to the additional cadmium cylinder can be accounted for by the reduction of the $1/v$ contribution to the effective resonance integral due to the larger effective cadmium cutoff energy. Another possible contribution to this worth decrease is the additional reduction in the fast-neutron source in the nearest fuel elements.

Reactivity measurements on gold have been extended to both higher and lower values of S/M for calibration of the oscillator. The higher values were obtained with four gold wires (each 0.030-in. diameter by 4.0-in. long), both closely packed and 0.25 in. apart, and with a single wire. Dancoff corrections were applied to the surface for the four-wire measurements to get the proper effective surface. The low S/M was obtained with a solid gold cylinder, 0.67-in. diameter by 0.67-in. high. These and previous results are presented in Table 5.

In Figure 5, worths per mole from these data are plotted against $\sqrt{S/M}$. A straight line fits the points well except for the thickest cylinder.

TABLE 5
EPICADMIUM REACTIVITIES OF GOLD SAMPLES

Diameter (in.)	Length (in.)	Epicadmium Worth (¢)
0.030	4.0	0.054
Four of above closely packed		0.183
Same, spaced 0.25 in. apart		0.225
0.235	3.683	1.195
0.67	0.67	1.136

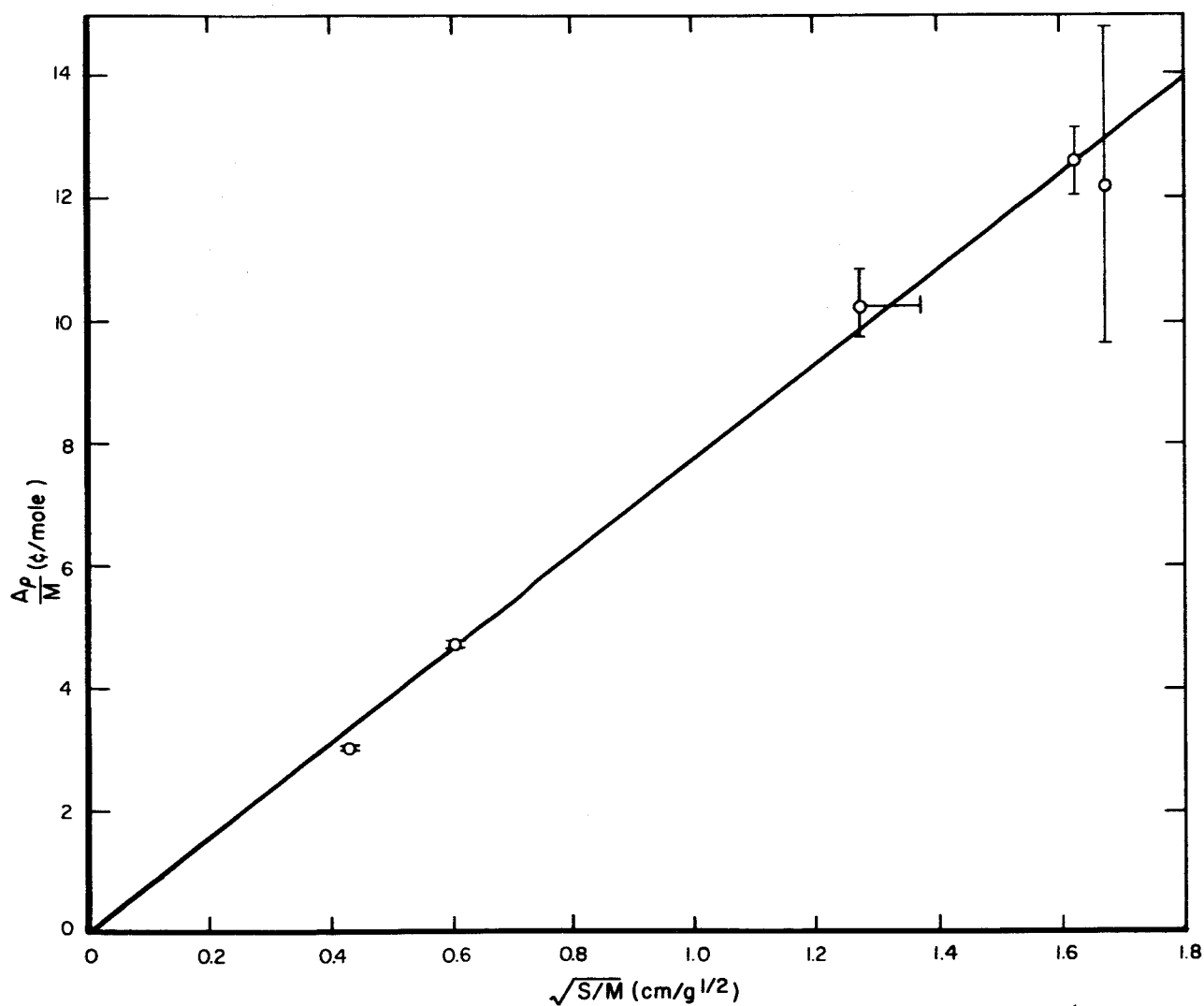


Figure 5. Reactivity per mole vs $\sqrt{S/M}$ for Gold

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Epicadmium worths of a number of U^{238} samples of varying dimensions, depletions, and densities were also measured to obtain an independent check of the oscillator calibration. Results are tabulated below.

TABLE 6
EPICADMIUM REACTIVITIES OF DEPLETED-
URANIUM SAMPLES

U ²³⁵ Content (%)	Diameter (in.)	Length (in.)	Epicadmium Worth (¢)
0.49	0.25	4.0	0.284
0.49	0.438 (OD)	4.0	0.528
	0.250 (ID)	-	-
0.22	0.438	4.0	0.758
0.22	0.4615	4.238	0.690*

*This sample was 85% of theoretical density.

Results of axial traverses of an Sb-Be source with the cadmium sleeve present showed that the shape of the adjoint flux for the source neutrons (25 kev) was unaffected by the sleeve, as expected.

All reactivities were determined by numerical integration of the neutron-kinetics equations, with the power history during oscillation as input data.⁽⁹⁾

c. Oxidation Experiment

An experiment was performed in which air was suddenly admitted to an oven containing a natural-tungsten sample at 1000°C. The discoloration observed on the sample, although pronounced, was localized near the air entrance. Metallographic examination of the sample indicated that the thickness of the oxide layer formed was less than 0.3 micron. It therefore appears that oven failure would produce little or no damage to a sample, an especially important consideration for the enriched samples.

C. RELATED PROJECTS (AEC-Sponsored Doppler Projects)

1. Advanced Doppler Coefficients

A total of 11 reactor runs to expose gold foils have been made with the improved multiple-sample apparatus. The range in S/M has been increased by a factor of three over the previous measurements and additional points have been obtained.

The RIFF-RAFF resonance-integral code,⁽¹⁰⁾ recently obtained from ANL, was adapted to run in the NAA computing system and has now been checked out. This code does not make use of the asymptotic-source assumption, and thus represents an improvement over TRIX or ZUT for treatment of the lowest gold and tungsten resonances.

One set of Doppler data from the original foil-wheel exposures has been completely analyzed. These data are in good agreement with TRIX calculations except at high S/M values, where some evidence of foil shadowing (eliminated in the new wheel) was observed.

2. Fast-Spectrum Doppler Measurements

Temperature-coefficient measurements have been made with samples of niobium, molybdenum, tungsten, lead, iron, and lavite in the standard (62-kev median fission energy) core and in several polyethylene blankets.

Comparison of Th with ThO_2 results and U^{238} with U^{238}O_2 results indicates that oxygen has little effect on the Doppler coefficients of the oxides of these two isotopes.

An alumina heater assembly, a mockup of a high-temperature thoria heater, has operated at 1570°K.

The reactivities of samples of thorium and tungsten have been measured from 300 down to 91°K (thorium) and 20°K (tungsten) with the aid of a Joule-Thomson refrigerator in the oscillator bar. The reactivity change for thorium is more than twice that obtained for the same temperature difference above 300°K. The tungsten data have not been analyzed yet.

A computer program has been prepared to determine the best temperature variation of the Doppler reactivity data. The computation is a least squares analysis based on the assumption that the reactivity change with temperature ($d\rho/dT$) varies as $T^{-\gamma}$, where γ is a parameter depending upon the neutron spectrum, and is expected to range from 0.5 to 1.5.

IV. ACTIVITIES DURING NEXT REPORT PERIOD

The RIFF-RAFF code will be used to examine problem areas in calculations of effective resonance integrals of tungsten and gold.

Final adjustments to the SGR-CA flux calculation will be made. Multigroup cross sections and resonance integrals will be calculated at several temperatures up to about 2500°K for actual isotopic compositions of enriched samples. These cross sections, together with the new SGR-CA fluxes and adjoints, will be used to calculate the sample Doppler coefficients.

Improved calculations of the thermal-expansion reactivity effect will be carried out.

Setup of the Monte Carlo calculation will be completed, and problem areas in tungsten and gold calculations will be investigated.

Resonance-integral and Doppler-coefficient reactivity measurements will be performed on enriched-tungsten samples. Activation measurements will be carried out on natural tungsten.

Flux mapping with resonance detectors will be completed and the results compared with those expected from calculated spectra.

The first high-temperature oven will be assembled and tested. If the tests are successful, additional ovens will be assembled and reactivity measurements will be extended to higher temperatures.

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